PATENT APPLICATION OF

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MULTIPLE SOURCE ALIGNMENT SENSOR WITH
IMPROVED OPTICS

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IMPROVED OPTICS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-In-Part
Application of U.S. Patent Application Serial No.
09/767,199 filed January 22, 2001 and entitled Improved
Laser Align Sensor with Sequencing Light Sources; The
application is also a non-provisional application of,
and claims priority to, U.S. Provisional Application
Serial No. 60/406,822, filed August 29, 2002 and
entitled Multiple Source Laser Align Sensor with
Improved Optics.

BACKGROUND OF THE INVENTION

The present invention relates to control
systems which align electrical components for precise
placement via pick-and-place machines onto surfaces
such as printed circuit boards, hybrid substrates
containing circuitry traces, and other carriers of
circuit tracings. More specifically, the present
invention relates to a non-contact light-based sensor
system which precisely determines angular orientation
and location (x, y) of components to allow a pick and
place machine to correct angular orientation of the
component with respect to the pick and place
machine's coordinate system for proper placement.

The electronic device assembly industry
uses pick and place machines to automatically "pick"
components from standardized feeder mechanisms, such
as tape reels, and "place" such components upon

appropriate carriers such as printed circuit boards.
A given printed circuit board may include a large
number of such components and thus the automation of
component placement upon the printed circuit board is
5   essential for cost effective manufacture. One
important aspect of a given pick and place machine is
the manner in which component orientation and
location are detected prior to placement. Some pick
and place machines transport the component to an
10   inspection station where it is imaged by an
inspection camera, or the like (i.e. off-head
systems). Once imaged, the controller, or other
appropriate device, calculates orientation and
location information from the component image. One
15   drawback associated with such systems is the added
time required to transport the component to the
imaging station; to image the component; and to
transport the component from the imaging station to
the placement location. Another type of pick and
20   place machine uses an "on-head" sensor to essentially
image the component while being transported from the
component feeder to the placement location. Thus, in
contrast to the above example, on-head component
inspection systems typically allow higher component
25   throughput and thus lower cost manufacture.

     Pick and place machines that incorporate
on-head sensors are known. One such device is taught
in U.S. Patent No. 5,278,634 issued to Skunes et al.,
and assigned to the assignee of the present

invention. U.S. Patent No. 5,278,634 discloses an on-head component detector that uses a single light source to direct illumination at and past a component of interest, which illumination then falls upon a

5   detector. The component fits through a fixed size window in the housing of the Skunes '634 sensor. With the light energized, the component is rotated by a vacuum quill while the width of the shadow cast upon the detector is monitored. The minimum shadow

10 width is registered when the sides of a rectangular component are aligned normally with respect to the detector. Associated electronics, sometimes resident in the pick-and-place machine, compute the desired rotational movement of the nozzle (with knowledge of

15 reference axes of the pick-and-place machine). This allows angular orientation of the component, as well as component position to be determined, and corrected for proper placement.

Other pick-and-place machines employ

20 sensors with multiple light sources in the sensor, to accommodate components of varying sizes.

Although the system taught by Skunes et al. has provided a significant advance to the art of electronic component placement in pick and place

25 machines, an efficient sensor adapted for use with components having a wide range of sizes would provide faster placement and less machine down-time to exchange sensors with different sized windows.

SUMMARY OF THE INVENTION

Features of the present invention provide an optical layout that can accommodate the relatively strict enclosure requirements for compact component
5   alignment sensor. Specifically, aspects of the present invention provide a single optical component that reduces the degree of divergence, and preferably substantially collimates light from the plurality of divergent light sources prior to entering the
10   component zone. In this regard, part count is kept low and the physical size of the optical train itself is relatively small.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a top plan view of a pick and
15   place machine of the present invention.

Fig. 1B is a perspective drawing of a sensor of the present invention.

Fig. 2 is a diagrammatic view of a system for detecting component orientation and location in
20   accordance with an embodiment of the present invention.

Fig. 3 is a diagrammatic view of a system for detecting component orientation and location in accordance with another embodiment of the present
25   invention.

Fig. 4 is a diagrammatic view of a system for detecting component orientation and location in accordance with another embodiment of the present invention.

Fig. 5 is a diagrammatic view of a system for detecting component orientation and location in accordance with another embodiment of the present invention.

5   Fig. 6 is a diagrammatic view of a system for detecting component orientation and location in accordance with another embodiment of the present invention.

Fig. 7 is a diagrammatic view of a system

10   for detecting component orientation and location in accordance with an embodiment of the present invention.

Fig. 8 is a diagrammatic view of a single detector source pair.

15   Fig. 9 is a diagrammatic view of a system for detecting component orientation and location in accordance with an embodiment of the present invention.

For convenience, items in different figures

20   having the same reference designator number are the same, or serve the same or similar function, as appropriate.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Fig. 1A is a top plan view of pick and

25   place machine 150 for which embodiments of the present invention are particularly useful. Although the description of Fig. 1A will be provided with respect to pick and place machine 150, other forms of pick and place machines such as split gantry designs,

can be used. As illustrated in Fig. 1A, machine 150
includes transport mechanism 152 that is adapted to
transport a workpiece such as a printed circuit
board.   Transport mechanism 152 includes mounting
5   section 154 and conveyor 156.   Transport mechanism
152 is disposed on base 158 such that the workpiece
is carried to mounting section 154 by conveyor 156.
Feeder mechanisms 160 are generally disposed on
either side of transport mechanism 152 and supply
10   electronic components thereto.   Feeders 160 can be
any suitable devices adapted to provide electronic
components.

Pick and place machine 150 includes head
162 disposed above base 158.   Head 162 is moveable
15   between either of feeder mechanisms 160 and mounting
section 154.   As can be seen, head supports 164 are
moveable on rails 166 thereby allowing head 162 to
move in the y direction over base 158.   Movement of
head 162 in the y direction occurs when motor 170, in
20   response to a motor actuation signal, rotates ball
screws 172 which engages one of head supports 164 to
thereby displace the support 164 in the y direction.
Head 162 is also supported upon rail 168 to allow
head movement in the x direction relative to base
25   158.   Movement of head 162 in the x direction occurs
when motor 174, in response to a motor actuation
signal, rotates ball screw 176, which engages head
162 and displaces head 162 in the x direction.   Other
pick-and-place designs, even those which do not

operate exclusively in x and y movements, may be adapted for use with the present invention.

Head 162 generally includes body 178, nozzle mount 180, nozzles 182, and sensor 184.

5   Nozzle mount 180 is disposed within body 178 and mounts each of nozzles 182 within body 178. As used herein, "nozzle" is intended to mean any apparatus capable of releasably holding a component. Each of nozzles 182 is movable in the z direction (up/down),x

10   and y directions, and is rotatable about the z axis by any suitable actuation members, such as servo motors. Sensor 184 is adapted to acquire shadow information related to components held by nozzles 182. Sensor 184 includes suitable illumination

15   devices and detection devices such that sensor 184 can provide shadow information that varies based upon component orientation and off-set. Sensor 184 can be mounted on head 162, or alternatively sensor 184 can be mounted at a fixed location with respect to head

20   162. The information provided by sensor 184 to processing electronics 34 is used to calculate respective component orientations and offsets. Such information includes calculating offset in the x and y axes as well as rotational offset.

25   Fig. 1B shows sensor 184 separately, with sources 12, 14, 15. Component(s) fit partially within sensing field 31, and obscure illumination from each of the successively energized sources as it falls onto a detector 24. Electronics 26 receive a

plurality of outputs from the detector as a nozzle (not shown) rotates the component. Electronics 26 may be partially located outside of sensor 184 in a pick-and-place machine.

5   Fig. 2 is a diagrammatic view of component orientation and placement detection system 10 in accordance with an embodiment of the present invention. System 10 includes sources 12, 14 which are arranged to direct illumination 16 upon component

10   18 from at least two different angles. Sources 12, 14 can be any suitable light sources as long as they provide illumination of sufficient intensity, as considered from each source. Thus, sources 12, 14 can be sources incoherent or coherent illumination.

15   Preferably, sources 12, 14 are laser diodes, but in some embodiments, sources 12, 14 are light emitting diodes (LED's). Sources 12, 14 can be positioned to provide illumination in substantially the same plane, as defined by either of the sources and two points on

20   the detector (a beginning and an ending pixel on the detector). Although a pair of sources 12, 14 are shown, any suitable number of sources, such as three sources, can be used. Illumination 16 from sources 12, 14 is blocked, to some extent, by component 18 to

25   thereby generate shadows 20, 22, respectively, on detector 24 which is preferably a linear charge coupled device (CCD) sensor or a Complementary Metal Oxide Semiconductor (CMOS) sensor. Detector 24 includes a number of photoelectric elements, or

pixels. Detector 24 essentially captures shadows 20, 22 in a brief instant of time and provides data (e.g. detector output) related to the captured shadow image to detector electronics 26 via link 28. As desired,

5   additional optical components (e.g. lenses, prisms, etc.) may be placed in front of the detector 24 so that the image of the component (the imaged or focused shadow) is incident upon detector 24, which then provides detector output representative of the

10 shadow image rather than the shadow. As used herein, "shadow" is intended to mean any representation that is generated in part by light of intensity that varies based upon at least partial obstruction by a component of interest. Thus, a shadow may or may not

15 be focussed before falling upon a detector.

As component 18 is held, or otherwise affixed to nozzle 30, component 18 is rotated as indicated by arrow 32 while sources 12, 14 are selectively energized. As can be appreciated, during

20 rotation of part 18, shadows 20, 22 will change size and position based upon the cross sectional area of component 18 obstructing a given beam 16 of illumination. The signal from detector 24 is read, and/or stored during rotation of component 18 such

25 that data from detector 24 is used to compute rotational orientation of component 18 as well as location (x, y) of component 18 with respect to nozzle 30. Detector electronics 26 provides this data to processing electronics 34 via link 36. As

illustrated in Fig. 2, processing electronics 34 is also preferably coupled to source control electronics 38 such that processing electronics 34 controls energization of sources 12, 14 during rotation of
5 component 18. Source control electronics 38, or energization electronics 38, is mounted within sensor 184 in some embodiments. Processing electronics 34 can reside within a suitable personal computer and includes appropriate software for computing angular
10 orientation and offset. Processing electronics 34 is also coupled to encoder 40 such that processing electronics 34 is provided with a signal from encoder 40 that is indicative of angular orientation of nozzle 30. Thus, by essentially knowing which
15 sources are energized, knowing the angular orientation of nozzle 30 as indicated by encoder 40, and by detecting images of the shadows cast by component 30 while rotated, processing electronics 34 computes component orientation and location, given
20 suitable knowledge of the internal geometry of the sensor.

Fig. 2 shows a double-edged measurement, as considered with respect to either of sources 12, 14, since shadows of two edges of component 18 fall on
25 detector 24.

Various embodiments of the present invention are designed to be able to extract component information (part size, center offset, and angular orientation, etc.) using either single edge

or double edge measurements of the component under
inspection. Typically, double edge measurements are
used when the dimensions of the component allow the
shadows of both component edges to fall upon the
5   detector during the same component measurement time,
without overlapping, as illustrated in Fig. 2. Thus,
at least two edges of the component can be shadowed
onto the detector by different sources within the
same component measurement time. The difference
10   between single edge measurement and double edge
measurement is that during the single edge
measurement process, only one edge of the component
is shadowed by any source onto the detector due to
the component being so large that the shadow of the
15   other edge of the component would not fall on the
detector.

Two or more sources are sequenced to reduce
elapsed time before image information is collected
for computation. This is particularly advantageous
20   when these sources are spaced separately with respect
to the plane that is defined by the sources, and the
CCD or imaging array (see, for example, Fig. 1B).
Since the sources are generally at differing angular
positions from each other relative to a line drawn
25   from nozzle 30 normal to the surface of detector 24,
each of sources 12, 14 will have its principal ray
directed at a different angle with respect to this
normal line as incident onto component 18. As used
herein, the principal ray is that ray emanating from

the center of the illumination generated by the radiation source, nominally referenced from the mechanical axis of the detector body, such that the core of emanated radiation, (which is typically
5 symmetrical) is bisected by the principal ray. This allows the information included in the shadow, such as edge information, to represent a different spatial position of the component, i.e. the edge of one side may be lined up with respect to the source 12 and, in
10 less than 90 degrees of component rotation another side may be lined up with respect to source 14, as illustrated in Fig. 2.

      The light sources 12, 14 are sequenced in any suitable manner. For example, sequencing sources
15 12, 14 at the full frame readout rate of detector 24 (e.g. 2 kHz line read-out rate), reduces the amount of time that elapses between these sources being sequenced such that the amount of angular rotation of the component during that interval is relatively
20 small. By sequencing the sources so, shadow images derived from either source individually can be obtained such that the movement of the component between any particular shadow image can be reduced, thus reducing the granularity and enhancing the
25 resolution of the sequence of images from that particular source. Each source allows collection of shadow images from a different rotational position of the component. Based on the different source locations with respect to the component, shadow

images from more than one angular position of the
component are collected within a relatively small
time.   The component information can be collected in
less time than would be required if a single source,
5   were energized to collect the data since full
rotation of the component would be required in order
to obtain the angular information.

Another important feature of embodiments of
the present invention is the ability to create a
10   measurement envelope, or sensing field of varying
dimension.   As used herein, a "sensing field" is a
cumulative space illuminated by the energized sources
in the sensor (when all sources are energized), as
modified by any mechanical obstruction such as a
15   housing.   Thus, a sensing field need not even require
a mechanical housing.   The sensing field is formed
by accommodating a plurality of sources positioned
such that a single sensor can sense orientation for
components of varying size.   For example, if a
20   component is 25 millimeters from side-to-side then
one energized source, placed 12.5 millimeters from
the nominal center of the component and disposed
normal to the detector with its principal ray, would
capture the edge of the component that was rotating
25   in the sensing field. This embodiment, in its
simplest form, requires only one energized source per
component size.   The sources have a specified solid
cone angle of light emitted from them so the distance
from the nominal center and lateral or roughly

parallel to, the detector surface as discussed above can be adjusted to account for this divergence of the source light in order to cast a shadow of the edge of the part. However, a source that is placed with its
5 principal ray pointing at, for example, an 8 millimeter position from nozzle 30 and along the diameter of the component 18 parallel to detector 24 would be blocked, depending on the relative orientation of the solid angle of light as well as
10 the position of the source. Based upon the solid angle of each source 12, 14, and the component size, each source will illuminate various sections of the component. It is important to select which one or more of the plurality of sources to energize, since
15 differently sized components mandate the use of different sources to generate even a portion of a shadow. Source control electronics 38 can also provide selective source energization based upon anticipated component size. However, source control
20 electronics can provide varying energization sequences for components of the same size in order to expedite processing, or provide additional information about the components.

As components are exchanged from small to
25 larger parts in the same sensor, sources having principal rays that are pointed increasingly further along a line parallel to, or lateral from, detector 24, but measured from a line normal to detector 24, through nozzle 30 or the center of rotation of the

component will image increasingly large components'
edges by selectively sequencing sources 12, 14. (See
arrow A in Fig. 1B). Preferably, sources 12, 14 are
sequenced to cast shadows from opposite sides of
5   component 18 in the same component measurement time
interval (in the case where each source casts a
shadow of a side). Selection of an appropriate
source allows the source, generally based on a priori
knowledge of expected part size, to be turned on
10 such that an edge of component 18 can be imaged onto
the detector 24. This allows components of varying
sizes to be imaged on detector 24 without requiring
the use of multiple sensors that are of a fixed
measurement envelope, or sensing field.

15   Although the description above has focused
on embodiments where a single nozzle is disposed
within the sensing field, other embodiments can
provide any suitable number of nozzles in the sensing
field. Fig. 3 is a diagrammatic view of system 20
20 for detecting component orientations in accordance
with another embodiment of the present invention.
System 20 includes many of the same or similar
elements as system 10 shown in Fig. 2 and like
elements are numbered similarly. Fig. 3 illustrates
25 that more than one nozzle 30 can be disposed in the
sensing field 31, such that multiple component
orientations and the locations can be imaged
substantially simultaneously in order to reduce
processing time.

The sensing field 31 is the area between the radiation (light) sources, and the detector, where components placed upon the nozzles will have light directed upon them. In this embodiment,

5 shadows from the components' edges are cast upon detector 24. Depending upon the locations of nozzles 30 and sources 12, 14, a particularly sized component 18 is measured by sequencing the various sources 12, 14, etc. such that shadows of the component 18 can be

10 distinguished from shadows of components on other nozzles. Source 12, 14 time sequencing is shown in Fig. 3 where electronics 38 energizes source 12 first, and then energizes source 14. This has an advantage of allowing more than one component 18 to

15 be measured in the sensing area at essentially the same time. Further, depending upon the spacing of nozzles 30, the nozzles can hold components of varying sizes, yet still allow measurement of the component to be accomplished while such components

20 are rotated on the nozzles.

Fig. 3 is an example of a double edged measurement, as considered with respect to sources 12, 14, since shadows of the two edges of component 18 fall on detector 24.

25 Fig. 4 is a diagrammatic view of component measurement system 50 in accordance with another embodiment of the present invention. Fig. 4 illustrates a sensing field 31 where detector 24 comprises two spaced-apart detector portions 24A,

24B, each one of which receives light incident from a specific source 12, 14. Detector portions 24A and 24B can be disposed adjacent to one another at a variety of angles, since each source detector pair

5 operates independently. The principal axis of detector 24A need not be in the same plane as the principal axis of detector 24B. Moreover, detector portions 24A and 24B can be arranged to image shadows from different parts of the component. Using separate

10 detector portions allows for the use of smaller detector portions, and, if necessary, allows the detector portions 24A, 24B to be packaged separately. In this manner, a very long detector 24 is not required in order to establish the same large

15 component sensing envelope or field 31. However, sequencing of sources 12, 14 is essentially the same as in the previous embodiment.

Fig. 4 is an example of a double edged measurement as considered with respect to sources 12,

20 14, since shadows of two edges of component 18 fall on each of detectors 24A, 24B.

Fig. 5 is a diagrammatic illustration of component measurement system 60 in accordance with another embodiment of the present invention. System

25 60 bears many similarities to system 50, shown in Fig. 4, and like components are numbered similarly. The main distinction between systems 60 and 50 is the relative orientations of detector portions 24A and 24B. Specifically, referring to Fig. 4, faces of

detector portions 24A and 24B lie in approximately the same plane, and when viewed in two dimensions, appear co-linear. However, system 60, shown in Fig. 5, illustrates detector portions 24A and 24B disposed

5 such that the principal axes of detector portions 24A and 24B do not lie in the same plane. Thus, detector portions 24A and 24B of system 60 do not appear co-linear with respect to each other. Instead, detector portions 24A and 24B are disposed normal to a

10 centerline of illumination from the respective source for each detector portion. For example, detector portion 24A appears to be oriented relative to source 14 such that ends 62 and 64 are equidistant from source 14. Detector portion 24A is also disposed in

15 the plane of shadow 20, and source sequencing operates as shown in the relative timing diagram in Fig. 5. Although detector portions 24A and 24B are shown disposed at a relatively slight angle with respect to each other, any suitable angle such as

20 ninety degrees can be used.

Fig. 5 is an example of a double sided measurement, as considered with respect to each source, since shadows of two edges of component 18 fall on each of detectors 24A, 24B.

25 Fig. 6 is a diagrammatic view of component measurement and detection system 70 in accordance with another embodiment of the present invention. System 70 is similar to the embodiment shown in Fig. 2 and like elements are numbered similarly. The main

distinction between systems 70 and 10, in Figs. 6 and
2 respectively, is the provision of specular
reflective surfaces 72, 74. As can be seen, sources
12, 14 direct their illumination away from detector
5   24 initially, which illumination falls upon specular
reflectors 72, 74, (typically substantially specular)
respectively, and is directed toward nozzle 30 and
detector 34. This embodiment allows for flexibility
in placement of sources 12, 14. Detector 24, as
10   shown in Fig. 6, could also incorporate either of the
detector layouts shown in Figs. 4 or 5. However, in
embodiments using split detector portions, and
specular reflectors, it is contemplated that one
source could utilize a specular reflector while
15   another source could be positioned so that its
principal ray is directly incident upon the
component, and thus not require a specular reflector.
Further, although Fig. 6 illustrates the use of
specular reflectors between sources 12, 14 and the
20   component, such specular reflectors could be disposed
between the component and detector 34.

        Fig. 7 is a diagrammatic view of component
measurement and detection system 80 in accordance
with an embodiment of the present invention. System
25   80 is illustrated to show how embodiments of the
present invention can be used to detect component
offset and rotational orientation for oversized
components (e.g. single edge measurements). This
discussion is provided to detail computation of

rotational and positional (x, y) offsets for single
edge measurements, and can be extended to double
sided measurements. U.S. Patent 5,559,727 to Deley
also provides for computation of rotational and
5   positional offsets for double-sided measurements with
a different light source/detector arrangement, and is
hereby incorporated by reference herein. Fig. 7 shows
an example of a single sided measurement with respect
to either of sources 12, 14, since only one shadow of
10   an edge falls on each of detectors 24A, 24B. Such
components are generally too large to fit shadows of
opposite sides simultaneously upon any single
detector portion.

Fig. 7 illustrates component 100 casting
15   shadows upon detector portions 24A and 24B. However,
each detector portion only captures a single shadow,
because component 100 is so large that the shadows of
its opposite sides do not fall upon detector portions
24A and 24B. In this embodiment, detector outputs
20   28A and 28B are monitored while component 100 is
rotated in order to detect shadow minimums indicating
when respective sides of component 100 are aligned
with the a given ray emanating from either of sources
12, 14. For example, in the example shown in Fig. 7,
25   slight counter-clockwise rotation will bring edge 102
of component 100 into alignment with a ray emanating
from source 14. Such alignment will generate a local
minimum upon detector portion 24A. Although in Fig. 7
it appears that the detectors are positioned at right

angles to the sources, it will be understood that non-orthogonal positioning may also be employed.

To determine the x-axis and y-axis offset, the width of the component, the length of all of the sides of the component, and the rotational offset of the component in Fig. 7, consider the analogous example of one source-detector pair of Fig. 7 shown in Fig. 8. The length of the minimum width is measured by finding the distance, D_1, between shadow edge and detector point O_1. The distance D_1 is related to component dimension L_1 in the following manner. When the distance D1 is at a minimum:

Equation 1

$$\tan(\alpha_1 \_ side \_ a) = \frac{L_a}{B_1} = \frac{D_1 \cdot \cos(\phi_1 - 90°)}{A_1}$$

so

Equation 2

$$L_a = \frac{B_1}{A_1}(D_1 \cdot \cos(\phi_1 - 90°))$$

and

Equation 3

$$\alpha_1 \_ side \_ a = \arctan\left(\frac{D_1 \bullet \cos(\phi_1 - 90°)}{A_1}\right)$$

Equations for L_c and $\alpha_1\_side\_a$ can be derived similarly when side_c is rotated to a similar position as side_a in Fig. 8. The encoder and encoder electronics captures the encoder rotation, E_1, the D_1 is at its minimum. If the step size between successive encoder rotations is T, then the part

rotation encoder value when side_a is aligned to a reference axis of the pick and place machine is perpendicular to a major axis of detector 24b, is:

Equation 4

$$E_{aligned\_side\_a} = E_1 + \frac{\phi_1 - \alpha_1\_side\_a}{T}$$

Where $\alpha_1\_side\_a$ is the angle formed at point source 12 between the line to O_1 on detector 24b and the line to S_1, and θ_1 is the angle formed at source 12 between the line to O_1 on detector 24b and a reference axis in the pick and place machine. The width of the component, W_{ac}, can be calculated as:

Equation 5

$$W_{ac} = L_a + L_c$$

And the offset of the nozzle axis 30 (the axis of rotation) from the center of the part along the line W is given by:

Equation 6

$$F_{ac} = \frac{L_c - L_a}{2}$$

The computation process described mathematically by Equations 1-6 can be optionally repeated for the remaining two opposing sides of component 100, from which orthogonal width and offset can be computed. This process can be iteratively applied to the component 100, where the values L_a, L_b, L_c, L_d, (length of sides of component 100) can be derived from any sequence of available minimums cast by sources 12, 14 upon detectors 24b, 24a as determined by the sequencing of energizing of sources

12, 14 and the rotation of the component 100 with respect to these sources.

FIG. 9 is a diagrammatic view of a component orientation and placement detection system
5   210 in accordance with an aspect of the present invention. FIG. 9 is somewhat similar to FIG. 1, and like components are numbered similarly. System 210 includes sources 212, 214 which are arranged to direct illumination 216 upon component 218 from at
10   least two different angles. Sources 212, 214 can be any suitable light sources as long as they provide illumination of sufficient intensity as considered from each source. Thus, sources 212, 214 can be incoherent or coherent illumination sources.
15   Preferably, source 212, 214 are laser diodes, but in some embodiments, sources 212, 214 are light emitting diodes. Sources 212, 214 can be positioned to provide illumination in substantially the same plane, as defined by either of the sources and two points on
20   the detector (a beginning and an ending pixel on the detector).

Divergent illumination from sources 212, 214 passes through optical element 217 which functions to reduce the degree of divergence of the
25   illumination, and preferably substantially collimate, light passing therethrough. As illustrated, illumination passing through element 217 from source 212 forms a first beam 219 having a reduced divergence, while that from source 214 forms a second

beam 221 having a reduced divergence. Preferably, optical element 217 is a lens that can be either spherical or cylindrical. However, a cylindrical lens is preferred. The illumination emerging from element

5 217 is less divergent, providing a more compact ray bundle than would otherwise be present, thereby speeding computation of component alignment, since less component rotation is required. Additionally, those skilled in the art will recognize that optical

10 element 217 is disposed backwards from the optically ideal orientation. In this manner, element 217 provides a flat surface proximate the component zone 223. The provision of a flat surface by element 217 proximate the component zone provides a convenient

15 seal in system 210 against contaminants.

In accordance with one aspect of the present invention, filter 225 is disposed proximate detector 224 in order to reduce ambient light falling on detector 224. Filter 225 can filter based on

20 incident light angles, and/or wavelengths.

Those skilled in the art will recognize that for a four-sided component, complete component measurement can be effected in about 225 degrees of rotation (180 degrees to image both edges + 45

25 degrees maximum to image the first edge). This is significantly faster than requiring a complete component rotation.

In some cases, the pick-and-place machine may not have any a priori knowledge of component

size. In such cases, the machine can perform a "source scan" where a plurality of sources are sequentially energized to determine if any of the sources are disposed relative to the component to
5   cast at least one shadow portion on at least one detector. If such combination is found, component measurement and alignment can be performed with the selected detector/source combination(s).

Operation of embodiments of the present
10 invention generally involve the following steps. The first step is calibrating the source, nozzle and detector positions with respect to each other. There are a number of techniques that can be employed for this operation. For example, calculation of the
15 positions of the various sensor components can be performed by placing the sensor with test components fixed in position in a coordinate measuring machine and then using the coordinate measuring machine to identify the relative position of all of the test
20 components such that the position of the ray that is incident from the light source or sources onto the detector is known with respect to the nozzle position and detector position.

As a second step, the shadow or shadows
25 from each component cast upon the detector by light incident from the source or sources has a characteristic intensity profile that is processed to extract an edge. The edge position can be interpolated to subpixel position. Such interpolation

can be effected using any number of techniques including centroid calculation or curve fitting. This, then, relates a particular edge position to an encoder position and a known source ray position.

5   Then, the defined edge of the shadow provides an (r, θ) pair where θ is the position of the encoder that is on the nozzle shaft or attached to the nozzle shaft indicating its relative angular position, and (r,θ) is the distance from the source to the edge

10   position on the detector that defines the position of the component at that specific point in angular space and time. The (r, θ) pairs are collected during the rotation of the component on the nozzle. These (r, θ) pairs are used to derive, using known geometric

15   techniques as per Fig. 7 (r, θ, B_1) where θ is used with α to calculate angular part orientation, component information including: component width, component length, nozzle off-set of rotation center x, nozzle off-set of rotation center y, and the

20   angular position of a defined frame of reference of the component with respect to the nozzle angular position. With this information, the component location can be translated into the specific pick and place machine's frame of mechanical reference via

25   software and the component can be properly positioned to be placed upon its target location on the printed circuit board.

        Although the present invention has been described with reference to preferred embodiments,

workers skilled in the art will recognize that
changes may be made in form and detail without
departing from the spirit and scope of the invention.
For example, multiple portions of detector 24 could
5   be placed within the same plane or without the same
plane. Further, such detector portions need not be
physically adjacent but may be segments of detectors
such that the multiple nozzles' position with respect
to the light sources and detectors allow components
10 to be imaged on such detector portions based upon
selection of sources that are turned on with respect
to components and detector portions.